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ABSTRACT

A study involving 120 undergraduate students attending the University of St. Thomas in St. Paul (Minnesota) was undertaken to test the interactive effect of instructional strategy (structured versus constructed) with learner's prior domain knowledge in concept acquisition. Previous instructional design research on concept learning has focused on structured strategies (i.e., expository and practice presentations) for initial learning of concepts. The assumption has been that learners had no prior domain knowledge of the concepts to be learned. The propose of this study was to extend that research by investigating the interaction of instructional strategies with students who have prior domain knowledge. Six abstract programming concepts from the domain of structured languages were selected as the content for the learning program. Results indicate that learners with no prior domain knowledge learned concepts better with a structured strategy than with a strategy that forced learners to construct the necessary conceptual knowledge. In contrast, learners with prior domain knowledge performed better when required to construct the knowledge than did learners who experienced the structured strategy. The importance of learner prior domain knowledge is discussed as it pertains to the selection of instructional strategies. Two tables are included. (TJH)

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Structured Versus Constructed Instructional Strategies for Improving Concept Acquisition by Domain-Experienced and Domain-Novice Learners

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Abstract

This study tested the interactive effect of instructional strategy (structured versus constructed) with learner prior domain knowledge in concept acquisition. Previous instructional design research on concept learning has focused on structured strategies (i.e., expository and practice presentations) for initial learning of concepts: The assumption was that learners had no prior domain knowledge of the to be learned concepts. The purpose of this study was to extend that research by investigating the interaction of instructional strategies with students that have prior domain knowledge. Results of the study showed that learners with no prior domain knowledge learned concepts better ($p < .001$) with a structured strategy versus those who had to construct the necessary conceptual knowledge. In contrast, learners with prior domain knowledge did better ($p < .001$) when required to construct the knowledge versus the structured strategy. Discussed is the importance of learner prior domain knowledge in the selection of instructional strategies.

Structured Versus Constructed Instructional Strategies for Improving Concept Acquisition by Domain-Experienced and Domain-Novice Learners

Recent educational literature discusses the possible implications of constructionist learning theory for instructional design theory (e.g., Bereiter, 1990; Brown, Collins, & Duquid, 1989; Shuell, 1990). Constructionist theories for the most part view concept learning as a series of discoveries occurring within contextual experiences. As such, instructional design for concept learning would favor strategies in which learners construct by employing their respective knowledge bases the conceptual prototypes for previously unencountered domains of information. In contrast, instructional design theories (e.g., Gagné, 1985; Fleming, 1987) have long employed learning theories that approach acquisition of new concepts through a sequence of structured events (e.g., expository information followed by practice). However, neither of these approaches to instructional design consider directly the possible adjustment to their proposed instructional strategies based upon a learner's prior domain knowledge. In both approaches, transfer and/or restructuring of knowledge when learning new concepts is an elusive phenomena when proposing their respective instructional prescriptions.

Our purpose in this study was to test the instructional

strategies proposed by these two approaches when considering directly the issue of learner prior domain knowledge. Prior domain knowledge is defined as the learner having previously developed prototypes of a domain's abstract concepts within a specific subdomain. For example, within the domain of structured programming languages, a learner who has acquired the language of BASIC would be considered to have prior domain knowledge. Such a learner can be classified as experienced when they can demonstrate problem solving skills by employing the domain's abstract concepts. On the other hand, a learner without prior knowledge of a given domain can be considered a novice. We are proposing that, in instructional situations where learners are to acquire new concepts, selecting the appropriate instructional strategy should include recognition of the learners prior domain knowledge--not just the advocacy of a given instructional strategy approach.

Research findings have long supported the notion that concept learning moves from acquisition of concrete examples to abstraction of prototypes (Tennyson & Rasch, 1990). And, if within domain transfer is to occur, the prototypes must be activated in learning of new concepts (Bransford, Sherwood, Vye, & Rieser, 1986; Gick, 1986; Nelson, 1977; Tennyson, 1973; Wittrock, 1974). Concrete examples are specific instances of concept procedures and problems (e.g., in BASIC, you can print your name on a printer). A prototype, on the other hand, is an

abstraction of a given concept class (e.g., the understanding that you may write a computer program in any language to print your name on a printer). Further, a programming statement, such as Print (in BASIC), is necessary and it must be followed by what is to be printed. That which is to be printed may be a literal constant or string or a variable which is given a value at some other place in the program. Novices in a given domain may be familiar with concrete examples from a given domain (e.g., that computer languages can control what is printed) but experienced learners may be expected to retrieve domain prototype knowledge which may allow them to learn how to employ Print in another programming language. That is, unlike the novice, they can transfer their prior domain prototype knowledge of a given programming language to the learning of how to Print in another language.

To facilitate the learning of concepts (i.e., moving from concrete to prototype), structured instructional strategies are prescribed (Merrill, Tennyson, & Posey, 1992). However, given our purpose in this study to test the effect of prior domain knowledge on concept acquisition, we tested a constructionist approach with the structured. The structured strategy employed a sequence that first presented the information in an expository form (i.e., concept label, definition, best example and several worked examples) followed by interrogatory examples (Tennyson & Cocchiarella, 1986). The constructed strategy employed a

discovery format where the learner was required to construct the necessary conceptual knowledge when given only interrogatory examples. Using a computer programming language as the learning task, our hypothesis was that novice computer programmers learn a first language differently from experienced programmers because they have no prior knowledge of programming. Likewise, experienced programmers learn a second language differently from the novice because they are able to transfer prior programming concepts to the new programming language. Therefore, novices would learn a given set of new concepts better with a structured strategy than a constructed strategy. Whereas, experienced programmers, on the other hand, would learn the same set of concepts more effectively with a constructed format than a structured.

Method

Subjects and Design

All participants in the experiment were undergraduate students at the University of St. Thomas in St. Paul, Minnesota. Using a 2X2 factorial design, the two independent variables, instructional strategy (structured and constructed) and prior domain knowledge (novice and experienced) formed four treatment groups: novice-structured, novice-constructed, experienced-structured, and experienced-constructed. Each group was composed of 30 men and women between the ages of 19-21. A screening test was used to separate the experienced programmers from the

novices. The screening test was given to all subjects prior to their receiving the instructional treatment.

Learning Program

Six abstract programming concepts from the domain of structured languages were selected as the content for the learning program. These six concepts are as follows: (a) data types; (b) input/output; (c) order of operations; (d) logic flow: sequential, repetition, and conditional; (e) accumulator; and (f) steps in writing a program. These six domain concepts were presented within the context of learning Pascal.

The instructional booklet developed for this study followed the design strategies presented in Merrill, Tennyson, and Posey (1992). The booklet consists of expository content for each concept, including definitions, best examples, range of examples, nonexamples, and worked examples of problems and interrogatory practice problems. For both the expository and interrogatory sections, the sequence for examples is from easy to difficult.

The booklet's 94 pages consists of three lessons, with each lesson having an introduction, presentation of expository information, practice problems, and summary. At the end of three lessons is an interrogatory section with four parts. The first three subsections present partly worked problems. The fourth requires the participant to write an entire program. Solutions to questions and problems are provided for all interrogatory sections. The solutions are presented using a coaching technique

that points out key issues and relates the problem to the definition, best example, and nonexamples. This booklet formed the structured treatment materials.

The constructed treatment booklet is 29 pages and consists of four sections of interrogatory instruction. The booklet begins with an introduction followed by a description of Pascal, directions how to progress through the booklet, and the four sections. The interrogatory sections were taken directly from the structured treatment booklet with the expository materials bound as a separate set of materials and labelled reference.

Screening Test

To test for prior knowledge of the six domain-level concepts, a screening test was developed. The test consisted of ten items written at the comprehension, application, analysis, and synthesis levels. Validity testing was performed on the screening test by (a) confirmation by three independent content experts and (b) pretesting and posttesting 27 students in a college level course in BASIC. The mean score on the pretest was 1 with the posttest mean of 9. Variance on the posttest established the scoring scale as 7 or below as the range for a novice and 8 or above experienced.

A second evaluation of the test was done to check for reliability of the instrument, the scoring scale, and the inter-rater scoring. Participants within their respective instructional treatment groups were assigned to the two

instructional formats as follows:

Novice. Participants included in the two novice groups received a scaled score of 7 or less on the screening test. Additionally, these participants had no prior formal coursework in computer programming languages.

Experienced. Participants included in the two experienced groups received a scaled score of 8 or above on the screening test. Additionally, these participants had a minimum of one computer programming course in BASIC.

Posttest and Retention Test

The posttest and retention test consisted of ten problems each. As with the screening test, these two tests were tested for validity and reliability. Three independent computer science experts confirmed the content with reliability testing with an introductory computer science class.

Procedure

The experiment consisted of four separate time periods: Screening test, instructional period, posttest and retention test. At the start of the first period, each student was given the WAIS arithmetic reasoning subtest (used as a covariate in the data analysis). After completing the WAIS, the screening test was given. Each student completed the test in 10-15 minutes. The screening tests were scored and participants, classified as either novice and experienced, were randomly assigned a treatment condition.

During the second period, students were segregated into four different rooms depending on the treatment group and classification. In each treatment group, the participants were given instructional booklets and asked to record the starting time. The experimenter introduced the theme of the instruction and read aloud the specific treatment directions while the participants read along silently. Participants then opened their respective instructional booklets worked separately until finished. Participants were able to take breaks at any given time because of the variable time required per instructional treatment. The instructional completion time varied from 60 minutes to 240 minutes (four hours). When finished, participants recorded their time and turned in the instructional booklet and received the posttest (start and finish time was recorded on the test by the participant). Two weeks later, the fourth period, the retention test was given (time was again recorded).

Results

The data analysis consisted of analysis of variance (ANOVA) with the Student-Newman-Keuls mean comparison test to determine treatment mean differences. The three dependent variables were correct posttest scores, correct retention test scores, and time-in-instruction. Because prior research studies have suggested that mathematical reasoning ability may affect pretest and/or posttest programming scores, an examination of scores on the WAIS arithmetic reasoning test was performed. A two-way ANOVA was

performed on these scores to determine whether arithmetic reasoning needed to be used as a covariate.

Covariate analysis. The ANOVA showed equality in group variances. Group 1 (novice-structured) showed a variance of 2.08, group 2 (novice-constructed) showed 2.03, group 3 (experienced-structured) showed 2.09, and group 4 (experienced-constructed) showed 2.32. The Cochrans C test resulted in non-significance, $p < .817$. The ANOVA also revealed nonsignificance of mean scores across groups (prior domain knowledge, $p < .182$ and instructional strategy, $p < .867$). Therefore, due to the homogeneity of the mean scores, an analysis of covariance was not necessary.

Screening test. There was a significant difference on the screening test between the experienced participants ($M = 9.30$) and the novices ($M = 1.15$), $F(1, 116) = 55.82$, $p < .001$, $MSe = 140.50$. These finding confirmed the evaluation of the test that it was measuring the six abstract concepts associated with structured programming languages.

Posttest

The ANOVA showed significant main effects for the posttest scores (Table 1). For the independent variable of prior domain knowledge, the experienced participants had a mean correct score ($M = 8.47$) of over two points higher than the novices ($M = 6.08$), $F(1, 116) = 86.89$, $p < .001$, $MSe = 170.41$. For the instructional strategy main effect, the structured format mean posttest score

(M = 8.27) was also two points higher than for the constructed (M= 6.28), $F(1, 116) = 60.17$, $p < .001$, $MSe = 118.01$.

Insert Table 1 about here

In terms of the interaction effect, the ANOVA showed a significant difference, $F(1, 116) = 96.88$, $p < .001$, MSe = 190.00. To analysis the group differences, we used a Student-Newman-Keuls test. The result was an ordinal interaction with the two novice groups being significantly different, $p > .05$. The novice-structured group showed a high level of learning, equal to that of the two experienced treatment groups. Performance by the novice-constructed participants indicated learning well below the criterion level of 80%. There was no difference between the two experienced treatments, $p > .05$.

Retention Test

On the retention test given two weeks after the posttest, the ANOVA showed a significant main effect for the prior domain knowledge variable. Novices (M = 7.28) increased their scores by one point over their posttest while the experienced participants showed no change (M = 8.24), $F(1, 116) = 10.74$, $p < .001$, MSe = 27.08. In contrast to the posttest results on the instructional strategy variable, there was no difference between the two treatment conditions: structured, M = 7.82; constructed, M = 7.70, $F(1, 116) = .162$, $p < .688$, $MSe = .41$.

Although, there was no difference on the main effect for

instructional strategy, there was a disordinal interaction, $F(1, 116) = 16.60$, $p < .001$, $MSe = 42.01$. Using the Student-Newman-Keuls test, we found that even though the novice-constructed group showed over a four point improvement from posttest to retention test, the mean score was still below criterion and significantly difference from the other three, $p < .05$. On the other hand, the experienced-structured group had a slight decrease in mean score from posttest to retention test which resulted in a significant difference with the experienced-constructed group, $p < .05$. Thus, the disordinal interaction was in the favor of the constructed instructional strategy, where the novice group improved significantly ($p < .05$) in performance from posttest to retention test and with the experienced group maintaining their high level of performance. There was no difference between the novice experienced groups in the structured condition.

Time-in-Instruction

The ANOVA on the total instructional time showed significant main effects. Novices ($M = 148.75$ min.) spent, on the average, 14 min. longer in the instruction than the experienced participants ($M = 134.75$), $F(1, 116) = 4.62$, $p < .03$, $MSe = 5,880.00$. Likewise, the main effect of instructional strategy showed that the participants in the constructed treatment ($M = 128.25$ min.) spent 27 min. less in the instruction than the structured treatment groups ($M = 155.25$), $F(1, 116) = 17.20$, $p <$

.001, MSe = 21,870.00.

Insert Table 2 about here

On the interaction test, F(1, 116), p < .02, MSe = 6,900.83, with the follow-up Student-Newman-Keuls, the experienced-constructed group spent 37% less time during instruction than either of the two structured groups and 30% more efficient than the other constructed group. The importance of these data is the relationship with performance. For example, the experienced-structured group spent over a third more time with the instruction than the experienced-constructed group but had a significantly lower performance on the retention test. When looking at the novice-constructed group which spent almost 10% less time in instruction but had a significant increase in performance on the retention test.

Discussion

Contemporary cognitive psychology has advanced the theory that learners can construct in memory new knowledge when faced with problem solving situations. What is unclear from an instructional design point of view, which considers both effective and efficient instruction, is how a learner is to acquire previous unencountered concepts when the learner has measurably no necessary knowledge to construct new knowledge. Constructionist theory maintains that the learner is quite capable of constructing new knowledge by employing their existing

knowledge base. However, there is conflicting empirical findings that show learners can use existing knowledge if sufficient contextual cues are available but when the learner has no or minimal understanding of the contextual situation, they fail to learn.

Previous research by Tennyson and associates (for literature reviews see Tennyson & Park, 1987; Tennyson & Cocchiarella, 1986; Tennyson & Rasch, 1988) has demonstrated that concept learning is improved when employing a structured set of instructional variables and conditions. Thus, there is a contrast between two possible approaches to the design of instruction for concept learning. Both approaches are supported by theory and research, however, neither approach has considered directly the importance of learner prior domain knowledge in the acquisition of knowledge. The structured approach assumes that the learner has no prior domain knowledge, therefore, the entire instructional paradigm rests on the assumption that the learner has to first acquire declarative and procedural knowledge of a concept before engaging in complex problem solving (i.e., contextual skill). Contextual skill is defined by Tennyson and Rasch (1988; 1990) as knowing when and why to use a given concept. On the other hand, the constructionist approach assumes that the learner has the necessary requisite knowledge and that the appropriate instructional paradigm consists of situational or contextual problems.

Given lack of research on prior domain knowledge by proponents of structured instructional design and the still unresolved problem in the constructionist theory on situations when the learner has no prior domain knowledge, our purpose was to test the two approaches when controlling for prior domain knowledge. The findings clearly indicate that both instructional strategies can result in a high level of concept acquisition. But, more important is that the findings also clearly show that selection of an instructional strategy should be in large part based on individual learner's prior domain knowledge.

Learners with no prior domain knowledge in the structured treatment condition spent slightly more time during instruction (less than 10%) but achieved learning at equal level with the experienced learners. Performance of the novices in the constructed strategy condition showed minimal improvement from pretest to posttest even after spending almost as much time trying as the learners in the two structured strategies. The increased performance by these learners on the retention test could be attributed to a slow pace of constructing knowledge resulting from test taking. A continuing increase would not be expected because their answers where for procedural knowledge and not for declarative or contextual. That is, they were figuring out how to solve some simple problems but they did not understand why and could not deal with the more complex problems.

The findings here also support some of the failures within

constructionist research by distinguishing the role of direct prior domain knowledge in concept learning. The experienced learners in the constructed strategy were both efficient in learning and in retention. Our explanation here is that by employing prototype knowledge, experienced learners can construct new concepts and further elaborate and improve their prototypes. That their prototype knowledge was improved was evident in the maintenance of their high level of performance on the retention test.

The findings in this study should help in the advancement of instructional design theory by supporting the concept of design first discussed by Gagné (1965) that different learning outcomes require different instructional strategies. This concept was further updated by Tennyson and Rasch (1988; 1990) when they extended Gagné's model to include instructional strategies developed from the cognitive psychology paradigm. We can now offer an additional component to instructional design theory that considers more focused cognitive assessment of learner knowledge when designing instructional strategies. Because contextual skill knowledge includes more that just the cognitive domain, future research should further test the effect of specific prior domain feelings (Harré, 1984), motives (Dweck, 1986), and values (Breuer, & Kummer, 1990).

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Table 1

Means and Standard Deviations for Correct Scores on Posttest and Retention Test

	Instructional Strategy			
	Structured		Constructed	
Prior Domain Knowledge	Posttest	Retention test	Posttest	Retention test
Novice				
M	8.33	7.93	3.83	6.63
SD	1.06	1.85	1.65	1.67
Experienced				
M	8.20	7.70	8.73	8.77
SD	1.71	1.66	.94	1.04

Note. Maximum criterion test score = 10.

Table 2

Means and Standard Deviations for Time-In-Instruction

Prior Domain Knowledge	Instructional Strategy	
	Structured	Constructed
Novice		
M	154.67	142.83
SD	34.93	33.97
Experienced		
M	155.83	113.67
SD	30.96	36.52

Note. Time is reported in minutes.